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Experiments were conducted in the field and laboratory in Southern California to determine the effects of heavy black asphaltic Santa Barbara crude oil on the intertidal barnacle Chthamalus fissus. Observations were also made on surfaces in the Santa Barbara Channel oiled following the 1969 Santa Barbara oil spill.

The data presented support the original hypothesis that this type of oil acts as a black body. It is this "black body" effect which has a long term influence on Chthamalus fissus distribution after the oil has developed a hard surface crust. This is based on the following observations:

1. larvae can settle, survive, and grow on the dry oil (tar)
2. larvae prefer a black surface to a light surface
3. temperature stresses are greater on a black surface than on a light surface.

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July 1976

TEMPERATURE EFFECTS OF CRUDE OIL IN THE UPPER INTERTIDAL ZONE

by

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FOREWORD

When energy and material resources are extracted, processed, and used, these operations usually pollute our environment. The resultant air, land, solid waste and other pollutants may adversely impact our aesthetic and physical well-being. Protection of our environment requires that we recognize and understand the complex environmental impacts of these operations and that corrective approaches be applied.

The Industrial Environmental Research Laboratory - Cincinnati assesses the environmental, social and economic impacts of industrial and energy-related activities and identifies, evaluates, develops and demonstrates alternatives for the protection of the environment.

This report describes work undertaken to determine the effect of black asphatic crude oil on species of barnacles in the intertidal zone of the Santa Barbara Channel. It was found that after an initial lag following exposure to the oil, barnacles reestablished themselves on the oil covered surfaces. This result suggests that in spill areas serious consideration should be given to leaving the oil in situ instead of using cleaning methods such as steam.

The results of this study should be of interest to biologists concerned with the effect of oil spills on aquatic life. Control agencies evaluating alternate cleanup methods should find the results useful.

David G. Stephan
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ABSTRACT

Experiments were conducted in the field and laboratory in Southern California to determine the effects of heavy black asphaltic Santa Barbara crude oil on the intertidal barnacle Chthamalus fissus. Observations were also made on surfaces in the Santa Barbara Channel oiled following the 1969 Santa Barbara oil spill.

The data presented support the original hypothesis that this type of oil acts as a black body. It is this "black body" effect which has a long term influence on Chthamalus fissus distribution after the oil has developed a hard surface crust. This is based on the following observations:

1. larvae can settle, survive, and grow on the dry oil (tar)
2. larvae prefer a black surface to a light surface
3. temperature stresses are greater on a black surface than on a light surface.

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SECTION I

CONCLUSIONS

Depression of intertidal larval settlement was observed in the upper intertidal zone among the Teredinae and algae.

Following the oiling of surfaces there was an initial lag phase during which the Chthamalus fissus larvae settle more abundantly on unoiled than oiled surfaces. This lasted approximately 2 months on fouling plates that were soaked in oil. Field observations suggest that the "lag" phase is slightly longer when rocky intertidal areas in Southern California are oiled following a spill of Santa Barbara crude oil.

After this "lag" phase, C. fissus larval settlement was more abundant on oiled than unoiled surfaces within the C. fissus zone. This trend was reversed when populations became very abundant.

In the upper regions of the C. fissus zone, C. fissus was more abundant on unoiled than on oiled surfaces. Oiled surfaces subject organisms to greater temperature stresses than unoiled surfaces through faster temperature changes at low tide and greater temperature fluctuations. As the larvae settle and survive abundantly on intertidal surfaces within the C. fissus zone, it is concluded that that temperature stress caused by the black surface of the oil at low tide caused high mortalities in newly settled C. fissus larvae resulting in reduced populations on oiled surfaces.

Lower in the C. fissus zone where temperature stresses were not as great, C. fissus populations recolonized oiled surfaces faster than unoiled surfaces.

Hence, within months of a surface being oiled by this type of oil, the oiled surface apparently acts like any other black surface in that it increases substrate temperatures at low tide and at high tide is more attractive to settling larvae that prefer a dark to a light surface.

SECTION II

RECOMMENDATIONS

The data presented in the report show that the presence of black asphaltic crude oils will change the distribution and abundance of species in the upper intertidal zone. Most of the changes studied can be attributed to a black body effect produced by the oil. However, all species studied were able to settle and survive on the oil and, in fact, in some instances the oil actually enhanced larval settlement. The greatest negative effects could be described as an initial lag phase after oiling when organisms did not settle on the oil and a lowering of the intertidal height of distribution of some species.

Most oil that strands intertidally, strands in the upper intertidal zone. Based on the data presented in this report, when oil of this type is stranded on rocks in the upper intertidal zone, serious consideration should be given to leaving the oil in situ rather than using methods such as steam cleaning which would produce greater environmental stresses than those demonstrated in this report.

SECTION III

INTRODUCTION

Field observations following the oil spill in the Santa Barbara Channel in January 1969, suggest that many of the effects of this heavy crude oil were of a physical nature rather than a chemical nature. Nicholson and Cimberg [7] reported areas where the barnacle, Chthamalus fissus was completely covered by a layer of oil while the taller barnacle, Balanus glandula, protruded through this layer of oil. The former were dead and the latter alive. C. fissus was apparently smothered under a thick layer of oil, while B. glandula was tall enough so that its cirri were active above the oil. Likewise, Chan [1] reported that Acmaea spp. were smothered simply because they were stuck to the substrate by a thick layer of bunker C oil. Hence, it is apparent that the physical effects of thick black oils deserve more attention.

The reports mentioned above are of a short-term nature - that is the animal becomes covered with oil at the time of the spill or shortly afterwards, and then slowly dies. The temperature effects of the oil are of longer term importance. The very fact that the substrate is now black suggests that at low tide, temperatures would be raised higher than normal. This rise in temperature may be the cause of some post-spill mortality. Organisms may be cooked and/or smothered in addition to being exposed to possible chemical effects.

The aim of this study is to investigate the temperature effects of such a heavy black oil in the upper intertidal zone. The work can be divided into three sections:

1. What effect does a tenacious black oil have on the substrate temperatures;

2. What effect does this black oil have on colonization of intertidal species on a solid substrate;

3. How does this black oil effect larval settlement and survival in C. fissus.

Preliminary work showed that substrate temperatures return to that of seawater at high tide. Hence, the oil only effects the substrate temperatures at low tide. Therefore, as the larvae will settle when the substrate is submerged (high tide), any temperature effects will be first

observed on the newly settled larvae at low tide. These temperature effects could be merely a rise in temperature, or if the oil were a thick layer, the residue could melt making it unstable.

Temperature is frequently the factor that limits the upper level of distribution of intertidal species. Therefore, raised substrate temperatures should result in lower upper limits of distribution of species settled on oil.

The working hypothesis is that after oil, high in asphaltene content, dries on a rocky substrate, effects on larval settlement are due largely to physical effects of oil. The barnacle Chthamalus fissus, which occurs in the upper intertidal zone, was the major organism chosen to test this hypothesis for several reasons.

1. The upper intertidal zone is exposed to the air and solar radiation for the longest period.

2. The upper intertidal zone is exposed to the greatest temperature fluctuations.

3. More is known about larval settlement in barnacles than in any other species of intertidal invertebrates.

4. Interspecific competition with other barnacles is avoided by choosing the uppermost intertidal species.

5. The author has background data on "normal" larval settlement patterns in C. fissus commencing early in 1969.

The background data revealed that there were two peaks in larval settlement in C. fissus - late spring and autumn. C. fissus settled at Catalina Island in May and September in 1969 and June in 1970. Larval settlement was also confined to periods of spring tides.

SECTION IV

MATERIALS AND METHODS

Santa Barbara crude oil from the Dos Cuadras offshore basin was used in all experiments. Field observations were conducted in areas where oil was present from the 1969 Santa Barbara oil spill and from natural oil seepage. These oils are all heavy black crude oils with an API Specific Gravity between 18 and 25 and a density between 0.90 and 0.95.

Periodic (monthly, when possible) surveys were conducted of temperatures on oiled and non-oiled surfaces at Goleta Point in the Santa Barbara Channel. These were on the top of a flat rock platform at an intertidal level equivalent to one between the two higher experimental levels at Santa Catalina. Other physical data such as surface composition and slope, as well as meterological data and the presence of other organisms were also recorded. These measurements were made at 50 points chosen from a random numbers table on the top of the flat rock platform at Goleta Point. The top of the platform approximates to mean high neap tide level. Temperatures were recorded using a Tele-thermometer Model 43TD (Yellow-spring Instrument Co.) and probes with a round flat surface that record on one side only. Actual substrate temperatures rather than an average of air and substrate temperatures were recorded by applying the recording surface to the substrate.

In the laboratory, rock surfaces were coated with Santa Barbara crude oil and exposed to a constant heat source. The temperature change was then recorded on the freshly oiled rocks, rocks oiled approximately 1 and 2 years previously, unoiled rocks, and pieces of tar and asphalt from Santa Barbara beaches. A 250-watt heat lamp, 70 cm above the measured surface, was used as a heat source.

Most field experiments were conducted at Santa Catalina Island to reduce complications caused by floating tar fouling experimental surfaces. At Santa Catalina Island, experiments were conducted on the south side (sunny side) of the Fishermans Cove pier. Wooden and asbestos surfaces were chosen for these experiments because, unlike many of the regularly used fouling surfaces (e.g., glass, plastics), these would absorb and retain the oil.

Series of paired smooth wooden stakes each 4 to 5 feet (1.22 to 1.525 m) long and 2 x 4 inches (5.1 x 10.2 cm) were used to study effects of Santa Barbara crude oil on the intertidal distribution of species. One of each

pair of stakes was coated with Santa Barbara crude oil and allowed to dry. The two stakes were then nailed together on the broad face. Stakes were positioned so that the broad face (10.2 cm wide) was against the pylon and an area 5.1 cm wide coated with oil adjacent to an area 5.1 cm wide not coated with oil, faced onshore. The stakes were in position in the intertidal zone within 4 hours of being coated with oil. Two such sets of stakes were used in each experiment in this series. One set was positioned so that the broad oiled side faced the pylon, and the other set was positioned so that the broad unoiled side faced the pylon (Figure 1). Each experiment commenced at a different time of the year so that settlement after different periods of leaching and at different seasons could be studied.

Figure 1. Experimental site at Santa Catalina Island. The chains are in position for attachment of asbestos fouling plates at three intertidal levels. Three sets of wooden stakes are in position. The oiled surface is the darker outer surface in each pair. The pair closest to the shore were exposed the longest and the middle pair the shortest period.

Photo - S. Christopherson.

The effects of Santa Barbara crude oil on C. fissus larval settlement was studied in the field using fouling plates. Fouling plates were made from 1/8 inch (2.5 mm) asbestos sheeting with perpendicular rows

of elongated depressions. The rows running in one direction are slightly larger and deeper than those in the other direction (2.2 x 0.8 mm versus 1.80 x 0.7 mm, respectively (Figure 2). These depressions were only present on one side of the fouling plate - the "pitted" side. The pitted side was used in all fouling plate experiments.

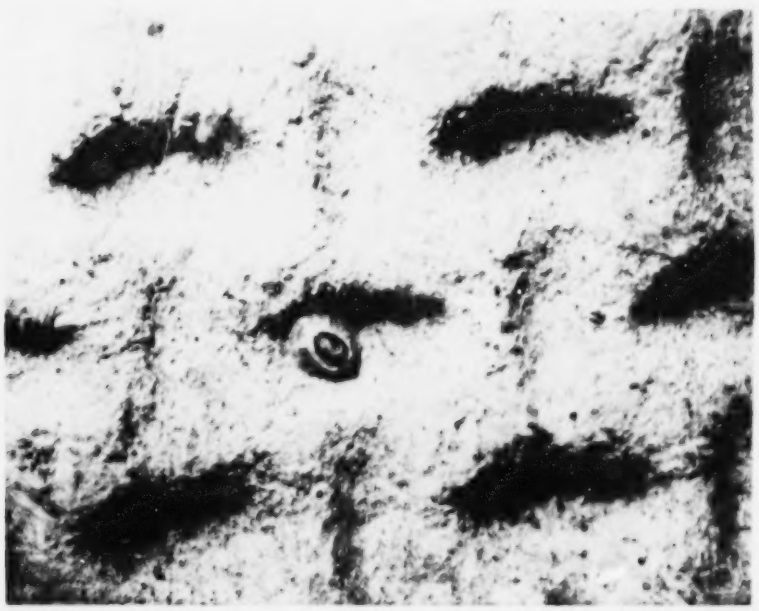

Figure 2. Young barnacle (C. fissus) settled on a pitted fouling plate. Scale (x 11)

Photo - R. Cimberg.

Asbestos fouling plates with pitted surfaces were placed in position at three different intertidal levels (Figure 1). Each plate was divided in half lengthwise and half coated with oil and half unoiled. Oiled surfaces were dried before being placed in the field. Plates were renewed at different time intervals so that the effects of leaching of both oil and substrate on larval settlement could be determined. Larval settlement as well as mortality and/or loss rates were studied through the daily mapping of the position of barnacles on fouling plates at low tide during periods of larval settlement and less frequent mapping between periods of larval settlement.

Each fouling plate (7.8 x 10.2 cm) had a hole drilled in the top. Ten fouling plates were then suspended from a plastic rack by placing a wire through the rack and hole in the top of the plate. The exposed area of the fouling plates was approximately 7.8 x 7.8 cm. Fouling plates (Figure 3) were placed so that the pitted side faced the same direction in all cases. This was outward from the pier and had a south-westerly aspect.

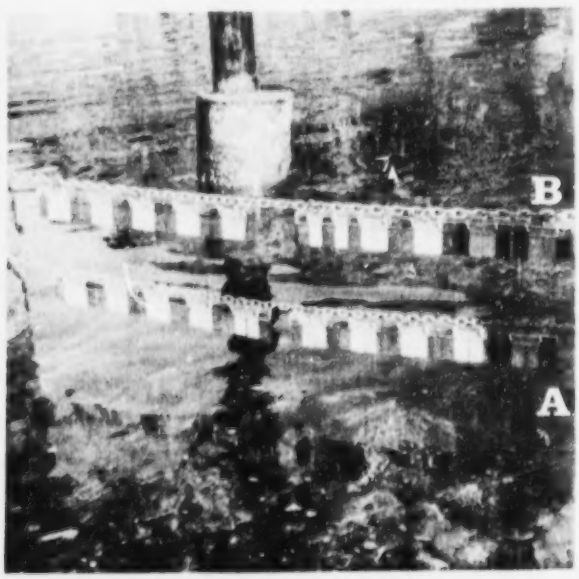

Figure 3. Series A and B asbestos fouling plates. On each plate the oiled half is the darker half.

Photo - S. Christopherson.

Logistically it was not possible to suspend plates at all three levels between the same set of pylons. Twenty plates were placed at each of the two most inshore levels (series D and C respectively). Series B (20 fouling plates), which is the same level as Series C, and Series A (20 fouling plates), which is the lowest level, were placed seaward of Series C and D (see Figure 1).

Examination of the pylons suggested that larval settlement may be influenced by distance offshore. Hence, Series B and C were placed at the same level to account for this factor. Settlement on the

fouling plates was analyzed using a Spearman Rank Correlation Coefficient [9].

Series D extended slightly above and within the upper area of C. fissus on pylons, Series B and C are lower and well within the C. fissus zone on pylons, while Series A is below the C. fissus zone on the pylons. The sag in the chain between pylons was negligible so that the vertical distance between fouling plates in each level was approximately 30 cms.

During spring tides (periods of C. fissus larval settlement) fouling plates were examined daily. This examination was made in the field using a hand lens as soon as the fouling plates were exposed by the following tide. If larvae were visible, the fouling plates were taken to the laboratory and the settling larvae counted and mapped under a binocular dissecting microscope. Fouling plates were returned to the field prior to their normal submergence by the rising tide. During periods where no settlement occurred, drift kelp was removed from the fouling plates when necessary (daily, during and after storms) because it would retard larval settlement.

Surface temperatures using the equipment listed previously were recorded on oiled and unoiled fouling plates at the three different levels and at different levels and sides of the wooden stakes.

Additional data on the relative abundance of larval settlement on oiled and unoiled surfaces, as well as the influence of intersite environmental variables on larval settlement, was obtained through a third series of field experiments in the Santa Barbara Channel.

These were conducted on the west side of the public fishing pier in Goleta County Park. The pier faces south so that the west side is in the sun in the afternoon. A 3/8-inch (0.95 mm) galvanized chain was fastened between two pilings near the end of the west side of the pier. It was placed just above the mussel band (predominately Mytilus californianus) on the pilings, at approximately the +1.0 foot tide level. Many Chthamalus were observed on the pilings at this level. This approximates to level A in the experiments at Santa Catalina Island.

Two series of fouling plates were used - one series of small plates which were identical to those used at Santa Catalina Island, and a second series of larger plates (10.2 x 15.4 cm). These large plates were cut from a second asbestos sheet with the same "pitted" configuration as that used at Santa Catalina Island. Half of each large fouling plate was dipped in crude oil (Figure 4) and allowed to dry 24 days. Plexiglass racks held 8 of these plates, 4 on each side (Figure 4, b and c). These were attached to the chain with # 12 galvanized wire in three places per rack. The plates slide into the grooves from the end of the rack and were held in place by cords tied around the ends of the rack.

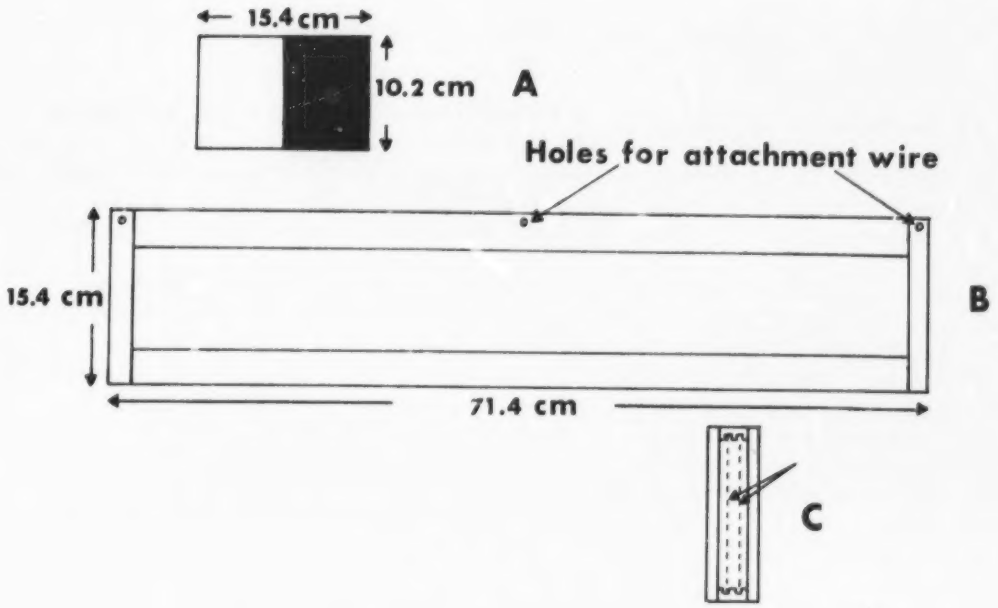

Figure 4. Fouling plate (a) and frame (b,c) design used at Goleta Point. b is front view of fouling plate frame and c is a cross section of the fouling plate frame. Size is shown in cm.

Four large or eight small plates were put into each rack using random numbers to determine which side, right or left, was oiled for each plate. The pitted side of the plate faced out on both sides of the rack.

On 11 November, 1972, five racks (A_1 - A_5) were hung on the chain. Rack A_1 was all small fouling plates, rack A_2 had 2 small and 3 large fouling plates per side, and the remaining 3 racks (A_3, A_4, A_5) contained all large fouling plates. This made a total of 20 small fouling plates and 30 large fouling plates, half of which were on the sunny side of the rack and half on the shaded side of the rack. Each fouling plate was labeled with red epoxy paint along the upper edge with a number and the letter of the rack. The racks were also marked front and back - the front was exposed to the sun during low tides while the back was shaded by the front.

A maximum-minimum thermometer was attached to each side of rack A_3 and checked daily during larval settlements. The actual temperature of individual plates was measured during the low tide on 19 November, 1972 using a tele-thermometer.

Initially the same techniques were used at Goleta for recording larval settlement and clearing the fouling plates of debris as were used at Santa Catalina Island. On the large fouling plates, a strip 13 mm wide on either side of the oiled - unoiled interface was not examined for larval settlement.

Larval settlement was more abundant at Goleta than at Santa Catalina Island making it impossible to count all settling larvae on a single low tide. A photographic technique was developed to overcome this problem.

A Pentax camera with a short extension tube was mounted on a ring stand 8-10 inches (20.4 - 25.5 cm) above the plates so that one small or half a large plate almost filled the field of view. Lighting was with a Vivitar Speedlight 32 strobe attached to the camera and hand held beside it. The film used was Kodak Kodachrome II. The slides were projected on a smooth surface and barnacles counted.

The settling barnacles were counted with the aide of a microscope during the first two periods of larval settlement (November 20-22, 1972, and December 5-8, 1972). Several fouling plates were photographed on November 21 and 22, 1972, to test this technique. All the counting on 19 December, 1972, and 15 January, 1973, was with the aid of photography. Barnacles were counted by eye marking each with a felt pen on 13 February, 1973, because they were no longer partially hidden in pits.

Chemical analyses were conducted to determine the initial composition of the petroleum used in the experiments and the changes that occurred prior to Chthamalus settlement. The following gas chromatographic conditions, similar to ones recommended by R.K. Kreider [6] were employed:

columns	2, stainless steel, 10 feet x 1/8 inch, packed with 80/100 mesh Chromosorb W (AW-DMCS), coated with 10% OV-101.
instrument	Hewlett Packard Model 700 Gas Chromatograph
injector	250°C
detector	dual flame ionization at 370°C
flow	Helium, 30-40 ml per minute
attenuation	10-8 to 10-10 AFS
chart speed	1/4 inch per minute
integration	disc
temperature	120° to 320° at 5°C/min

All samples were injected into the instrument without prior column chromatography either neat or as solution in carbon disulfide. Before each day's run, the resolution was checked by observing splitting between n-C_{17} and pristane in reference standards and columns were balanced to eliminate baseline drift. An end temperature of 320°C allowed components of 35 or less equivalent carbon numbers to be eluted from the column.

Various solvents and combinations of solvents were used for the initial extraction of fouling plates which had been coated with crude oil. The results obtained using these solvents and solvent combinations, and extraction times employed with a Soxhlet apparatus are shown in Table 1.

TABLE 1.

COMPARISON OF PETROLEUM EXTRACTION BY DIFFERENT SOLVENTS

Extraction	Time	Comments
Methanol	24 hr	greatly increased concentrations of n-paraffins above C_{27}
Pentane	12 hr	greatly reduced concentrations of n-paraffins below C_{23}; colored band left on plate
Pentane, Methanol, Chloroform (1:1:1)	8 hr	identical to gas chromatographic finger-print of A-21 except for evaporation losses below C_{19}
Carbon disulfide	8 hr	identical to gas chromatographic finger-print of A-21 except for evaporation losses below C_{19}
Carbon disulfide*	8 hr	loss of volaitles up to C_{12}; skewing of base envelope C_{13}-C_{19}; C_{14}-C_{16} isoprenoid visible and abundant; pristane height greater than phytane height

*This sample was concentrated by rotary evaporation under reduced pressure.

All other fouling plates were extracted for 8 hours with carbon disulphide which was subsequently concentrated by rotary evaporation under reduced pressure.

To determine if there was any leaching of components from oiled to unoiled areas of fouling plates, plates were cut into six vertical sections, 3 oiled and 3 unoiled. If there was any leaching of components, one would expect a gradation across these sections with the clean section adjacent to the oil containing a higher concentration of oil than the clean section furthest from the oil.

The effects of temperature on newly settled larvae were tested in the laboratory. Fouling plates were aged in laboratory aquaria for a minimum of 2 weeks and then placed in the field for one high tide during periods when C. fissus were settling. The positions of larvae were plotted and the larvae placed in a constant environment chamber at a predetermined temperature for four hours. The fouling plates were then placed in running seawater for 12 hours and the larvae mapped again to determine survival. This was conducted in May 1972 and November 1972 and the temperatures used (25°C, 30°C, 35°C, 40°C, 41°C) in May and (27°C, 31°C, 44°C) in November were chosen based on substrate temperatures observed in the field. The time taken for the initial census plus the exposure time in the constant environment chamber approximated to the period when the plates would have been exposed at low tide. Hence, the only stress should have been that imposed in the constant environment chamber.

Field observations on intertidal areas at Campus Point, Goleta (approximating to levels B,C at Santa Catalina) determined the influence of asphaltic deposits on settlement and survival of C. fissus in the intertidal zone. The asphaltic deposits were up to 2.5 cm thick on a mesozoic monterey silicified shale formation.

On 11 November, 1972, 6 areas (1 inch square = 2.55 sq. cms) on the rocks at Campus Point, Goleta, at different intertidal heights and substrate angles in the upper intertidal area were selected. A 1x3 inch glass microscope slide was divided into thirds and the center third used for the experimental area. The locations on the rocks were marked by hammering stainless steel screws into the rocks so that the slot in the head touched the corner of the slide - two diagonal corners were marked for each location. Three of the areas had a hard dry asphaltic substrate and 3 plain rocks. All were in the sun during the afternoon. Four additional areas (2 with a hard dry asphaltic substrate, 2 with a rock substrate) were added on 21 November 1972. Barnacles were mapped by placing a labeled slide between the screws and marking on the glass with a diamond pencil. A hand lens was used to see small barnacles. The temperatures of the experimental areas as well as nearby rocks were measured using a Yellow Springs Tele-Thermometer. The areas were mapped on 12 November, 1972, 21 November, 1972, 2 December, 1972, 16 January, 1973 and 15 February, 1973, while temperatures were measured on 17 November, 1972, 20 December, 1972 and 15 February, 1973.

SECTION V

RESULTS

Experimental crude oil

The oil used in the experiments came from the Dos Cuadras field. Analysis by gas chromatography over the range C_{10} - C_{35+} showed it to be low in n-paraffins (5% of the oil) with only n-C_{13} - n-C_{27} being resolved. It is high in isoprenoids (almost 5%). The most dominant feature is the isoprenoid peaks C_{14}, C_{15} (farnesane), C_{16}, C_{18}, C_{19} (pristane), and C_{20} (phytane). This is essentially the same gas chromatogram as that obtained from A-21 oil spilled in 1969 in the Santa Barbara Channel (see Kanter [4] Figure 2).

The oil used in these particular experiments was obtained at the Mobil Tank Farm north of Ventura. This means that it could have been a mixture of oil from several producing platforms on the Dos Cuadras field. Oil from this field has a high asphaltic content. For example the general production from the upper zone which has an API Specific Gravity of 23 and 1.5% sulphur content has an asphaltic residue of 26.7% at 1025°F. This asphaltic residue (distillation bottoms) contains other components as well as asphaltenes.

The most typical oil, that is representative of the largest production in this field, has an API specific gravity of 26.7. The asphaltic fraction defined as the fraction remaining at 1025°F and above, was 21.45%. The asphaltenes amounted to 28.5% of the asphaltic material.

Analysis of Test Surfaces

The results of the analysis of oil and asbestos fouling plates by gas chromatography are presented in Table 2. Unoiled fouling plates contained some impurities suspected of being of petroleum origin. These obscured the low molecular regions so that small amounts of material migrating from the oiled surfaces would be undetected. These impurities probably came from production or cutting equipment used in asbestos manufacture. Analysis of the unoiled section of two fouling plates - one of which had been in the field for two months and one which had been in the field one month, showed no evidence of migration of large amounts of components of oil from the oiled section onto the unoiled section of the fouling plate.

TABLE 2

ANALYSIS OF DOS CUADRAS CRUDE OIL, OILED AND UNOILED FOULING PLATES (C_{10} - C_{35+})

Sample	Analysis
Dos Cuadras crude oil	Low in n-paraffins, only n-C_{13} - n-C_{27} resolved, less than 5% of the oil; high in isoprenoids, almost 5%, the most dominant feature, C_{14}, C_{15} (farnesane), C_{16}, C_{18}, C_{19} (pristane), and C_{20} (phytane) same chromatogram as A-21 spilled in 1969
Freshly oiled fouling plate.	Loss of volatiles upto C_{12}; skewing of base envelope C_{13} - C_{19}; C_{14} - C_{16} isoprenoid visible and abundant pristane height greater than phytane height.
Fouling plate in field 2+ weeks. Oiled section, outer edge of plate.	Loss of volatiles upto C_{12}; skewing of base envelope C_{13} - C_{19}; C_{14} - C_{16} isoprenoid visible and abundant pristane height greater than phytane height.
Fouling plate in field 2+ weeks. Oiled section, inner edge of plate.	Loss of volatiles upto C_{12}; skewing of base envelope C_{13} - C_{19}; C_{14} - C_{16} isoprenoid visible and abundant pristane height greater than phytane height.
Fouling plate in field 9 weeks. Oiled section, outer edge of plate	Loss of volatiles upto C_{12}; skewing of base envelope C_{12} - C_{20}; pristane height less than phytane height.
Fouling plate in field 9 weeks. Oiled section, inner part of plate.	Loss of volatiles upto C_{12}; skewing of base envelope C_{12} - C_{20}; pristane height less than phytane height.
Fouling plate in field 2+ weeks. Unoiled sections, outer and inner parts of plate.	Pattern and characteristics not of A-21; but some petroleum like impurity in the asbestos.
Fouling plate in field 9 weeks. Unoiled sections from outer and inner parts of plate.	Pattern and characteristics not of A-21; but some petroleum like impurity in the asbestos.
Clean fouling plate.	Pattern and characteristics not of A-21; but some petroleum like impurity in the asbestos.

The oiled sections of three fouling plates were analyzed. All violatiles up to C_{12} were lost on all fouling plates. The freshly oiled fouling plate had been oiled and air dried for 1 week. This and the other oiled fouling plates were maintained at -20°C from the time of preparation or collection in the field until analysis by gas chromatography. Some degradation had commenced on the freshly oiled fouling plate as indicated by the skewing of base envelope C_{13} - C_{19} but this had not advanced significantly after (2+) weeks in the field as indicated by analysis of a fouling plate that was exposed from (March 30 to April 17, 1972). However, when a plate that was exposed (February 14 to April 17, 1972) for 9 weeks was analyzed there was an increase in skewing of the base envelope C_{12} - C_{20} and the pristane height was now less than the phytane height - the reverse of the analysis of fresher oil.

Barnacle settlement was reported on the 9-week fouling plate on the oiled surface but not on the unoiled surface. No barnacle settlement was reported on the (2+) weeks fouling plate either from the oiled or from the non-oiled surface.

Effects of Santa Barbara Crude Oil on Substrate Surface Temperature

Both a faster increase in temperature and a higher temperature were recorded on the surface of oil or rock surfaces covered with oil (either immediately before or 1 year before the experiment), and on asphaltic surfaces than on the surface of unoiled rocks (Figures 5,6). The fastest and greatest increase in surface temperature was recorded on the surface of crude oil (Figure 5) whereas the slowest and lowest temperatures were recorded on the surface of a piece of sticky seep tar (Figure 6). The increase in temperature of the seep tar was erratic and almost stepwise. However, while the surface temperature increase on all other substrates took the form of a curve which flattened out after approximately 2 hours' exposure to the heat source (Figure 5,6), the surface temperature of the seep tar has more of a straight line form with the temperature still increasing after 4 1/2 hours' exposure to the heat source (Figure 5). Note that little rise in temperature was recorded on either the oiled or unoiled rock surfaces after the first 2 hours (Figure 6). This was further confirmed when experiments in 1972 were conducted over 4-hour periods. The maximum temperature increase during the third hour was 1°C and there was no increase in temperature during the fourth hour of any experiment Hence, the rise in temperature over the first 2 hours is considered indicative of the surface reactions to a heat source.

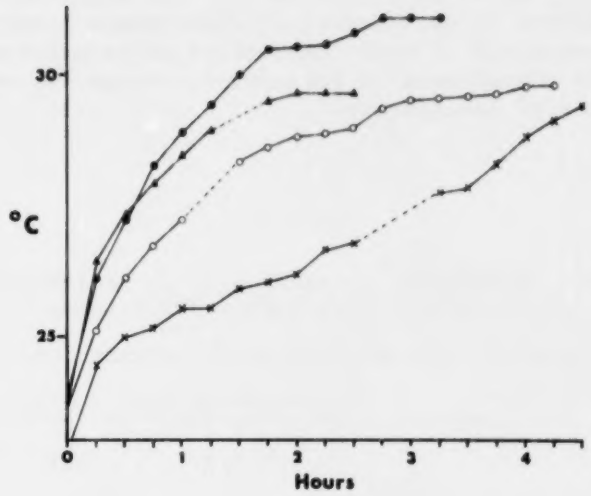

Figure 5. Surface temperatures recorded at 15 minute intervals on unoiled rock (0); freshly oiled rock (●); asphalt (▲); and sticky tar (X) (October, 1970). An infra-red light source was used.

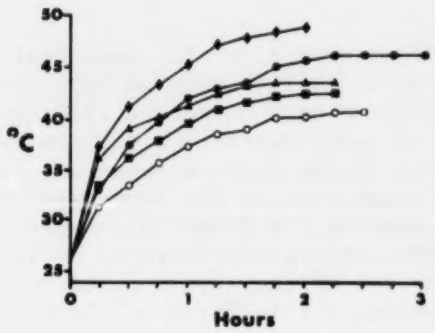

Figure 6. Surface temperatures recorded at 15 minute intervals on unoiled rock (0); freshly oiled rock (●); rock oiled 1 year previously (■); asphalt (▲); fresh oil (◆) (June, 1971. An infra-red light source was used.

These experiments were repeated over a 2-year period and on each occasion, the greatest increase in temperature over a 2-hour period occurred on freshly oiled rocks (Table 3). The magnitude of temperature increase differs in each series of experiments because the experiments were conducted at room temperature on each occasion. Therefore, direct comparisons of temperature change may only be made within each series of experiments.

TABLE 3.

SURFACE TEMPERATURE INCREASE (°C) AFTER EXPOSURE TO A CONSTANT HEAT SOURCE FOR 2 HOURS

Date	Condition of Rock Surface			
	Unoiled	Fresh Oil	1-Year Oil	2-Year Oil
October 1970	5.0	6.6		
June 1971	15.0	20.6	16.6	
12 October, 1972	11.0		12.1	10.5
31 October, 1972	12.0	12.7	12.4	10.9

The rock oiled in 1970 was exposed to the same heat source in 1971 (1 year oiled) and again in 1972 (2 year oiled); the rock oiled in 1971 was exposed to the same heat source in 1972 (1 year old). The rocks were maintained at room temperature for the intervening period. The temperature increase on the year-old rock was less than that recorded on the freshly oiled rock in the same experiment series but greater than that recorded on the 2-year oiled rock and unoiled rock of the same series. The temperature increase on the 2-year oiled rock was less than that recorded on the 1-year oiled rock and unoiled rock in the same series. Hence, a thin layer of black oil initially increases the surface temperatures recorded on rocks, but as the oil ages, even though it is still visible as a black surface, the surface temperatures over the first 2 hours of exposure to a heat source are actually lower than that recorded on unoiled surfaces. Asphalt always attained a lower temperature than the freshly oiled rock but a higher temperature than the unoiled rock in 2 hours of exposure to a constant heat source (Figures 5,6).

Surface temperatures on oiled and unoiled test surfaces at Santa Catalina Island and on a partly asphalt covered rock platform at Goleta Point in the Santa Barbara Channel were also recorded. Surface temperatures on oiled and unoiled surfaces of individual asbestos fouling plates showed that the average surface temperature was always higher on the oiled than the unoiled surface (Table 4). The plates present an over-simplification of normal field situations in that all surfaces measured were either all in the sun or all in the shade and the moisture content of the surface was approximately the same for the oiled and unoiled surface on each plate.

TABLE 4.

THE MAXIMUM, MINIMUM AND MEAN TEMPERATURE RECORDED ON FOULING PLATE SERIES C AT SANTA CATALINA ISLAND

Date/time	Oil	Nonoil	Δ *	N+
March 28 10.00	18.0-21.8;20.0	17.5-20.3;19.1	0.9	5
April 20 10.30	20.5-25.8;22.65	19.2-24.2;22.07	0.6	8
April 20 13.30	19.9-22.8;21.6	20.0-22.8;21.2	0.4	8
April 21 08.30	16.5-19.2;17.76	16.4-19.0;17.2	0.4	8
April 21 10.15	19.0-22.2;20.9	19.5-22.2;20.8	0.1	8
April 21 13.00	21.0-24.4;22.8	20.5-24.3;22.5	0.3	8
April 22 08.30	17.1-20.5;18.35	16.0-19.8;17.7	0.6	8
April 22 12.30	21.9-25.8;22.9	20.6-25.0;22.7	0.2	8
May 18 12.00	20.0-25.0;21.8	19.3-24.8;21.5	0.3	19
May 19 13.00	17.5-20.8;19.2	18.2-20.5;19.1	0.1	9
May 27 15.00	18.9-20.6;19.8	19.0-20.3;19.7	0.1	20
May 29 15.00	19.8-22.7;20.9	19.8-22.7;20.8	0.1	10
May 30 15.30	21.2-22.5;22.05	21.0-22.4;19.05	0.1	10

Δ* is the difference between the mean temperature on oiled and unoiled surfaces.

N+ is the number of paired readings.

There was a gradual decrease in the difference between oiled and not oiled surface temperatures as the plates aged (Table 4). As they aged, the oiled surfaces became lighter in color being dark black (March 28, 1972) at the commencement of the experiment, and a very pale brown by May 30, 1972. At the latter time it was sometimes difficult to distinguish the older oiled and not oiled surfaces in the field. The same was noted in experiments with asbestos fouling plates in the Santa Barbara Channel. However, oiled surfaces became darker when wet so that the differences with age referred to above at low tide, were not as great during high tide when the larvae would be settling.

Surface temperatures were recorded on the paired oiled - not oiled surfaces of wooden stakes over a period of several hours as the tide fell. These stakes were placed at different distances from the shore and had been in position for different periods of time. Hence, the oil had weathered to different extents and the oiled surfaces were now different colors. The stakes nearest and furthest from the shore were in position in the field 24 hours before the experiment and had dark black oiled surfaces; the stake second from the shore was in position 22 months and the oil was now only just visible on the surface; the stake third from the shore was in position 7 months and the oiled surfaces had lost some color - the color was intermediate between the oiled surface of the stakes in position 1 day and the stake in position 22 months.

Figures 7,8,9 show the surface temperatures recorded over a three hour period from the time the level of the Chthamalus zone was uncovered on the stakes until low tide. The paired surfaces are shown as those facing the shore (o) or those facing offshore (◇). The symbols are open when the surface was in the sun and black when the surface was in the shade.

Higher temperatures were always recorded on the oiled than on the un-oiled surface of stakes in the sun, in position for 1 day (Figure 7). The difference was much less on stakes in position for either 7 or 22 months - in the latter case the temperatures on oiled and unoiled surfaces were equal (Figure 8). Surface temperatures were lower in the shade than in the sun and were the same on oiled and unoiled surfaces in position 7 and 22 months (Figures (8,9). However, shaded oiled surfaces ranged from 0°C to 1°C higher than shaded unoiled surfaces in position for 1 day.

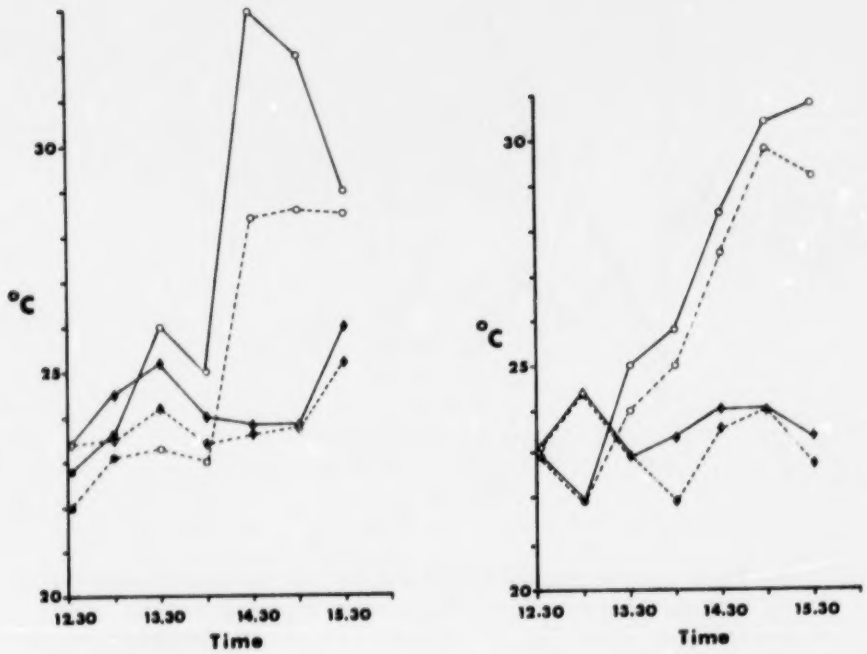

Figure 7. Surface temperatures recorded at 30 minute-intervals on wooden stakes after they were exposed in the intertidal zone for 1 day. - oiled surface; - - - unoiled surface. 0 indicates that the surface faced the shore; ◊ indicates that the surface faced offshore. Symbols are open when the surface is in the sun and black when the surface is in the shade

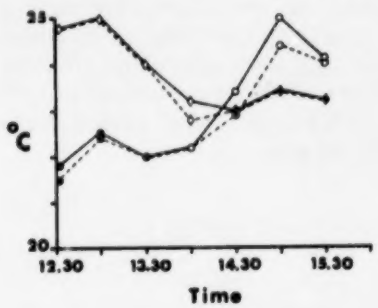

Figure 8. Surface temperatures recorded at 30 minute-intervals on wooden stakes after they were exposed in the intertidal zone for 7 months. - oiled surface; - - - unoiled surface. 0 indicates that the surface faced the shore; ◊ indicates that the surface faced offshore. Symbols are open when the surface is in the sun and black when the surface is in the shade.

Figure 9. Surface temperatures recorded at 30 minute-intervals on wooden stakes after they were exposed in the intertidal zone for 22 months. - oiled surface; - - - unoiled surface. 0 indicates that the surface faced the shore; ◊ indicates that the surface faced offshore. Symbols are open when the surface is in the sun and black when the surface is in the shade.

The wetness of the surface was also an important factor. In general surface temperatures were lower on wet than dry surface (Table 5). This is no doubt due to some evaporative cooling on the wet surfaces. On surfaces in the sun, both the temperature range and average temperature were lower on wet surfaces than dry surfaces. The relationship is not clear for shaded surfaces because only five temperatures were recorded on dry surfaces in the shade.

TABLE 5.

THE MAXIMUM, MINIMUM, AND MEAN TEMPERATURE RECORDED ON PAIRED OILED AND UNOILED WOODEN STAKE SURFACES AT SANTA CATALINA ISLAND, AUGUST 19, 1971

Condition	Wet	Dry
Oil / Sun	23.2-26.0 24.4	24.0-33.0 28.7
No Oil / Sun	22.8-25.4 23.9	24.0-29.8 27.2
Oil / Shade	20.8-26.0 23.2	22.0-24.0 23
No Oil / Shade	20.8-25.2 22.9	22.0-25.5 23.8

Temperatures were also recorded on the inshore stake at the level of the top of intertidal species and at the bottom of the stake to determine temperature differences at different levels of the intertidal zone at low tide (Figure 10). The top measurements were 40 cm above the bottom measurements. When the first temperatures were recorded the top level had a dry surface while the bottom level was wet and only exposed between waves. Thirty minutes later the waves were no longer reaching the bottom level. However, the bottom level remained damp during most of these observations and was only just dry prior to the last observation. Water temperature was 23.4°C. Bottom surface temperatures approximated to this (23.2°C-23.5°C) on the first observation. As the tide receded, temperatures rose over the next half hour by approximately 1°C in the shade 3°C in the sun at the bottom level.

Several factors as well as intertidal height must be considered in analyzing the data in Figure 10. They are sun versus shade; oil versus non-oiled surfaces. Surfaces in the sun consistently had a higher temperature than those in the shade. Oiled surfaces in the sun were always hotter than those in the shade.

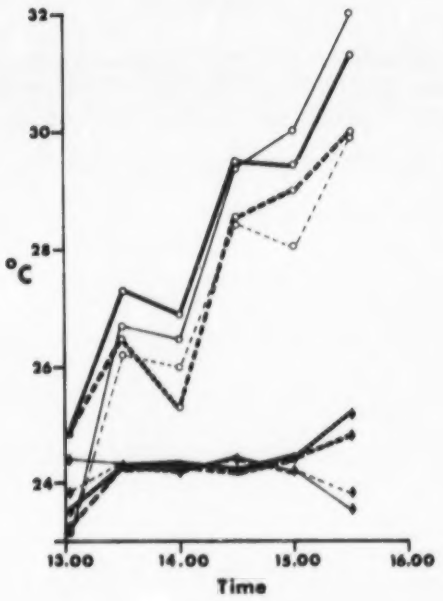

Figure 10. Surface temperatures of a stake at upper level (thick lines) of intertidal species and bottom (thin lines) of the stake. ○ indicates surface faces offshore; ◇ indicates surface faces onshore. Open symbols indicate the surface was in the sun; black symbols indicate the surface was in the shade. - indicates an oiled surface; --- indicates an unoiled surface.

The temperature was higher at the top level than the bottom level with the exception of two readings on the oiled surface in the sun. This is thought to be due to a temperature increase as a result of reflected heat from the near-by rocks after the surface had dried. The top level was further from the rocks and so less affected by them. Both temperature range (with the exception of the readings just discussed) and average temperature were higher at the top level than the bottom level (Table 6).

TABLE 6.

TEMPERATURES (°C) RECORDED AT THE TOP LEVEL OF INTERTIDAL ORGANISMS AND THE BOTTOM OF OILED AND UNOILED WOODEN STAKES

	Range		Mean	
	Top	Bottom	Top	Bottom
Facing Shore				
Oil	23.5-25.2	23.5-24.4	24.317	24.17
Non oil	23.2-24.8	23.8-24.4	24.2	24.117
Facing Offshore				
Non oil	24.8-30.0	23.2-30.0	27.35	27.06
Oil	24.8-31.3	23.2-32.0	28.16	27.9

Data for field temperatures on natural substrates is presented in Table 7 and Appendix 1. Table 7 shows that the highest temperatures were recorded on dry oiled surfaces in the sun and the lowest temperatures on wet oiled surfaces in the shade. This indicates that the presence of oil acting as a black body not only increases the maximum surface temperatures as shown by the laboratory as well as the field data, but it can increase the range of temperature to which organisms are exposed at low tide. It should be stressed that the difference in temperature between oiled and unoiled surfaces in the shade is seldom higher than 1°C, while in the sun it may be as high as 5°C. Also there is usually less than 1°C difference in temperature between wet oiled and wet unoiled surfaces in the sun. The exceptions occur when very shallow rock pools reach exceptionally high temperatures (Table 7).

TABLE 7

THE MEAN TEMPERATURES RECORDED ON NATURAL SURFACES AT GOLETA POINT.

Oil	No Oil	Sun	Shade	Wet	Dry	January 1972	February 1972	March 1972		April 1972		June 1972	December 1972		February 1972	
+		+			+	25.0	30.3	27.7	27.3	25.3	23.0	30.3	26.9	25.8	23.0	23.8
	+	+			+	_	29.5	24.8	24.2	19.8	23.1	26.8	25.4	25.6	21.6	22.9
+		+		+		22.3	25.9	24.4	29.0	21.3	24.3	25.3	_	_	_	_
	+	+		+		21.0	25.2	24.1	26.6	22.3	25.4	25.6	22.8	23.4	21.2	20.9
	+		+		+	_	_	_	19.8	16.0	_	_	23.0	23.2	19.1	20.0
	+		+	+		19.5	19.7	20.8	21.4	18.1	_	_	_	21.1	17.7	19.3
+			+		+	19.5	_	_	20.2	_	_	_	21.55	21.0	_	_
+			+	+		20.5	_	_	17.2	_	_	_	_	20.3	_	_

Effects of Santa Barbara Crude Oil on Substrate Color

Substrate color has frequently been demonstrated to influence larval settlement. Hence, some description of the color of test fouling surfaces is important. The freshly oiled wooden and asbestos surfaces were black. The colors are as defined in Ridgeway (1912). It should also be noted that there was some variability in surface substrate color due to factors such as slight differences in weathering which may be the result of exposure to different amounts of sand abrasion and/or the presence of a thin film of micro-algae. However, unoiled asbestos plates can best be defined as tilleul buff to pale olive buff in color. After 4 months' weathering oiled asbestos surfaces approached this color and indeed were often visually indistinguishable from unoiled surfaces when dry. These oiled surfaces sometimes had small patches of black residue left on parts of the fouling plates, sheltered by the frame. Asbestos fouling plates in the field for 1 month were generally dark-cinnamon drab, while those in the field for 2 months were characterized as light gull grey.

Oiled wooden stakes were weathered from black to vinaceous-cinnamon sometimes with streaks of black in 7 months, whereas in 10 months, they had weathered to pale pinkish cinnamon. Unoiled wooden surfaces approximated to this color also after 10 months. New unoiled wooden surfaces approximate to ochraceous-buff in color.

The colors were defined at low tide when the surfaces were dry. When the surfaces were wet, the oiled surfaces were darker so that fouling plates which had oiled and unoiled surfaces of a similar color at low tide, had an oiled surface darker than the unoiled surface when submerged.

The relationship between substrate color and temperature was examined on fouling plates at low tide in October 1972. The plates were visually divided into those with a dark oiled surface, those in which the oiled surface was only slightly darker than the unoiled surface, those on which the two surfaces appeared the same color. In the darkest category the oiled surface was hotest by 2.3-4.2°C $\left(\frac{45.5}{42.8}, \frac{46.0}{41.8}\right)$, in the slightly darker category, the oiled surfaces were warmer by an average of 1°C $\left(\frac{44.8}{43.8}; \frac{36.5}{35.7}; \frac{38.0}{36.8}\right)$ while in the category where the colors were similar the temperature was the same $\left(\frac{43.0}{43.0}\right)$. The fouling plates with surface temperatures in the 30°C range were damp while all other fouling plates were dry.

Larval Settlement

Four foot (1.22m) wooden stakes (oiled versus unoiled) were placed in the field to determine differences in the intertidal distribution of species due to the presence of oil. It was essential that all stakes remain upright to ensure that differences observed at a particular height were only influenced by environmental variables at that height. However, during storms both the force of waves and accumulating kelp often knocked stakes out of position making it impossible to relate the resulting populations to specific intertidal levels. While a total of 8 pairs of stakes were placed in the intertidal zone at different times to provide data to show any differences in seasonal and leaching effects, reliable data on species distribution are only available for 4 pairs of stakes. All stakes did provide data on surface temperature difference.

On the four pairs of stakes that had remained in position, the upper intertidal distribution of the dominant organisms was recorded in increments of 10 cm from the bottom of the stakes (Table 8). Therefore, heights are only comparable within paired stake surfaces and not between paired stake surfaces. Data for onshore and offshore paired surfaces is presented separately. While the data may differ between the offshore and onshore surfaces, there was essentially no difference in the upper intertidal distribution of Spirorbis sp., C. fissus, Balanus glandula, and Tetraclita squamosa on oiled and unoiled surfaces, while for the green algal film and the Teredinae the upper level of distribution was higher on the unoiled than on the oiled surface. It should be pointed out that the barnacle settlement was very sparse only 2 animals being present on many of the surfaces so that this data on barnacle settlement should be viewed as inconclusive.

In contrast the green algal film was abundant and being grazed by limpets (Collisella scabra and C. limulata). The Teredinae were also thriving having completely destroyed part of the 16 month unoiled stake. Hence, the data for these two groups is thought to provide an accurate description of this influence of the test crude oil on their intertidal distribution.

More definitive experiments were conducted using fouling plates. This data also records settlement and survival over long periods rather than settlement and survival immediately after settlement.

The fouling plates were placed in rows lengthwise along the outside of the pier in an attempt to equate physical factors effecting all the fouling plates. For example, they should all receive the same

TABLE 8.

MAXIMUM HEIGHT (CM) OF DISTRIBUTION MEASURED FROM THE BOTTOM OF THE WOODEN STAKE

Date and Exposure time	Green Algae		Spirorbis		C. fissus		B. glandula		T. squamosa		Teredinae	
	O*	U+	O	U	O	U	O	U	O	U	O	U
2/8/72	110	110		10	70				40		20	40
16 month	120	130	40	60	70	60	50	50	60**	60**	10	40
6 month	110	120				60	70		30	30	10	40
	100	120							20			
8/22/72	60	70	10	10					10	10		
8 month	50	60	20	20	20				20	20		
11/20/72	60	100			40	40***					135	
3 month	60	70			20							

*O = oiled

+U = unoiled

** 75 T. squamosa on oiled surface and 10 T. squamosa on unoiled surface.

*** At edge of unoiled stake next to oiled stake.

amount of exposure to the sun. If they had been placed in rows across underneath the pier they would have received exposure to varying amounts of sunlight and at different times of the day.

However, the arrangement used does mean that there is a gradation in the height of the fouling plates above the sand and rocks; those plates at the inshore end are closer to the sand and rocks than those at the offshore end. This could effect the larval settlement due to differences in exposure of the fouling plates to different amounts of abrasion.

To test this, a series of 32 asbestos fouling plates were suspended in a wooden frame along the side of the jetty. The number of C. fissus settling on the fouling plates in 5 months was counted. A Spearman Rank Correlation Coefficient [9] was calculated to determine if there was a correlation between the number of C. fissus settling and the order of the fouling plates in the frame (Appendix 2 for detail).

$$r_s = 1 - \frac{6 \sum_{i=1}^{N} d_1^2}{N^3 - N}$$

The Spearmen Rank Correlation Coefficient was 0.28, which was not significant. Therefore, it was concluded that this ordered arrangement of fouling plates did not bias the larval settlement.

Larval settlement was not abundant for most of the experimental period during 1972. Unpublished data showed that C. fissus settled most abundantly on spring tides usally in May and October at Santa Catalina Island. In 1972, settlement occurred in low numbers on spring tides from early April through early June and in early October and early December (See Tables 9,10). However, while in most instances, the total number of barnacles remains low, the trends of greater or less settlement on oiled and unoiled surfaces remain constant. As with the wooden stakes, fouling plates were sometimes lost. Hence, in all data comparisons the number of plates in each category is indicated. If one or two fouling plates were lost from a particular category it meant a reduction in the number of fouling plates considered in all categories to make the data comparable.

C. fissus was most abundant at the mid-level (B,C), least abundant at D with an intermediate abundance at A. This is demonstrated in Table 9 which shows total numbers of C. fissus on fouling plates at levels A,B,C,D for the period October 1972 to February 1973. There is also a general decrease in C. fissus throughout this period at all levels.

TABLE 9.

UNOILED

NUMBER OF C. Fissus ON OILED ASBESTOS FOULING PLATES AT LEVELS A,B,C,D AT SANTA CATALINA ISLAND

	Plate Series				
Date	A	B		C	D
6 October 1972	15	27	16	61	18
	72	245	98	374	6
15 October 1972	21	21	12	66	19
	82	235+++	117	216+	7
22 October 1972	20	25	15	62	12
	74	246+	102	235+	3
1 November 1972	22	26	13	54	8
	67	217++	99	207	1
17 November 1972	6		9	22	0
	49		83	132	0
20 November 1972	6		10	24	0
	41		76	108	0
2 December 1972	7		9	19	0
	46		99	116	0
15 December 1972	4		10	25	0
	38		77	90	0
2 February 1973	9		7	16	0
	17		54	73	0
No plates per level	19	19	10	19	10

+ indicates number of areas recorded as having 50+. These were very tiny C. fissus difficult to count in large numbers in the field.

At the beginning of October 1972 all fouling plates had been in the field a minimum of 5 months. In all cases at levels A,B,C, C. fissus was more abundant on the oiled than the unoiled surface. At level D the reverse was the case from October 6 through November 1. However, all C. fissus were dead by November 15 at level D and there was no recolonization prior to February 2, 1973.

Larval settlement occurred first at level A (April 10, 1972) and did not average even one larva per fouling plate per level at levels B,C, and D until May 19, 1972. Hence, studies on the minimal "lag" period between oiling and larval settlement were conducted at level A. Three ages of fouling plates were used - plate series O which was submerged 17 February 1972; plate series N which was submerged 30 March 1972; plate series F which was submerged 6 May 1972. All fouling surfaces submerged 6 weeks or less had more C. fissus on the unoiled than the oiled surfaces while those fouling plates submerged 8 weeks or more had more C. fissus on the oiled than the unoiled surface (Table 10). While these figures are in each case a composite of numbers on several fouling plates, this trend was also demonstrated on individual fouling plates.

TABLE 10.

UNOILED

NUMBER OF C. fissus ON OILED ASBESTOS FOULING PLATES AT SANTA CATALINA ISLAND LEVEL A

		Plate series			Week exposure
Date	No. plates*	F	N	O	F: N: O
11 April 1972	7		14/3	27/34	- 1: 8
21 April 1972	7		7/3	18/26	- 3: 10
18 May 1972	3	23/6	4/1	6/21	2: 6: 13
29 May 1972	5	21/10	6/9	5/23	4: 8: 15
6 October 1972	5	13/28	4/19	3/13	22: 26: 33
2 December 1972	5	10/12	3/12	1/9	30: 34: 41
2 February 1972	5	8/9	1/8	0/5	38: 42: 49

*No. plates refers to number examined in each plate series (F,N, or O).

T. squamosa first settled on asbestos fouling plates at level A in April 1972. They exhibit only two annual periods of larval settlement at Santa Catalina Island (spring and fall). The population was observed in detail between October 1972 and February 1973. T. squamosa was more abundant on the oiled than the unoiled surfaces throughout this period. There was little overall fluctuation in numbers and the ratio of T. squamosa on oiled to unoiled surfaces approximated 2:1 throughout (5363 oiled : 2836 unoiled).

B. glandula also settled on asbestos fouling plates at level A only. In October 1972 only four remained on oiled surfaces and three on unoiled surfaces while by February 1973 there were only two survivors on oiled surfaces and none on unoiled surfaces.

Fouling plates used at Goleta Point were of two categories. The first was the same series of fouling plates that were suspended at Santa Catalina in May of 1972. That is, these fouling plates were air dried for 6 months prior to exposure at Goleta Point. The other series were of a larger size and were oiled and air dried 3 weeks before exposure in the field.

C. fissus settled abundantly on the fouling plates at Goleta. They were more abundant on the surfaces oiled in May 1972 than the surfaces oiled in October 1972 (Tables 11,12,13,14). In most cases larval settlement was more abundant on the oiled than the unoiled surface. The exceptions were on the fouling plates oiled in May 1972. Larval settlement was most abundant on this surface (at times 1,400 C. fissus per fouling plate).

Calculation of the Spearman Rank Correlation Coefficient shows that rs = 0.718 when N = 14 (See Appendix 4 for details). This is significant at the 1% level. Hence, in very dense populations C. fissus is more abundant on unoiled than oiled surfaces. Settlement was less dense on the fouling plates oiled in October 1972 and was always more abundant on the oiled than the nonoiled surfaces.

A similar calculation of a Spearman Rank Correlation Coefficient on the data from Santa Catalina presented in Table 10, shows no correlation between total number of larvae settling and the distribution of larvae on oiled and unoiled surfaces (Appendix 5).

While data in Tables 11,12,13,14 are presented for surfaces in the sun and shade, it must be pointed out that the surfaces faced opposite directions and so were probably subjected to different water currents at high tide and different drying effects of winds at low tide. Hence, comparison of settlement on the two surfaces would provide little insight into the causal factors influencing larval settlement.

There was no significant larval settlement of other barnacle species at Goleta, but occasional balanoid cyprids and newly settled barnacles were observed on fouling plates. There was an initial abundant

TABLE 11

NUMBER OF C. fissus LARVAE SETTLING ON SUNNY FOULING PLATES (OILED OCTOBER 1972) AT GOLETA

Date	Plate Numbers													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
20 November 1972	10/281			4/309	2/282									
21 November 1972				2/368	5/327						16/291	4/213	1/213	
22 November 1972				3/370	3/335	4/358	13/320	4/316	8/412	6/354	2/218	1/214		6/216
5 December 1972				28/722	31/611	31/572	105/600	25/660	8/409		96/922	88/801		31/788
6 December 1972	26/788	88/873	182/841											
19 December 1972	25/819	97/857	173/830	33/700	49/655	39/627	138/665	45/660		82/742	116/863	97/843		61/800
15 January 1973	151/734	174/868	138/908	92/774	127/673	114/632	182/666				219/949	229/920		286/813
13 February 1973	91/788	170/820	211/792											

* Number on nonoiled/number on oiled surface

TABLE 12

NUMBER OF *C. fissus* LARVAE SETTLING ON SHADED FOULING PLATES (OILED OCTOBER 1972) AT GOLETA

Date	Plate Numbers													
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
20 November 1972				1/183	6/166									
21 November 1972	20/162			4/156	6/179			18/360			3/315	10/269		
22 November 1972				5/193	3/192	4/175	4/328	10/294	5/191	24/224	2/257	6/289	1/256	35/290
5 December 1972								30/410			45/561	45/555	75/609	217/825
6 December 1972	38/428	18/322	76/513	24/314	8/315	28/328	9/542	46/396	29/313					
19 December 1972		30/357	75/518	41/366	19/391	17/377	19/553	103/479	109/389		59/641	55/601	79/599	224/789
15 January 1973		161/450	216/578	122/366							198/607	188/662	218/671	325/921
13 February 1973		268/559	344/606											

* Number on nonoiled/number on oiled surface

TABLE 13

NUMBER OF *C. fissus* LARVAE SETTLING ON SUNNY FOULING PLATES (OILED MAY 1972) AT GOLETA

Date	Plate Numbers 1	2	3	4	5	6	7	8	9
20 November 1972	77/256	70/243	19/142						
Total	333	313	161						
21 November 1972	93/273	88/276	12/312				27/170	416/414	157/289
Total	366	364	324				197	830	346
22 November 1972	85/218	50/200	0/169	27/295	35/273	18/216	30/160	644/426	455/471
Total	303	250	169	322	308	234	190	1070	926
8 December 1972	363/600	380/736	197/672	210/661	229/787	127/596	155/528	783/678	611/699
Total	963	1116	869	871	1016	723	683	1461	1310
19 December 1972	380/595	384/737	221/665	232/684	250/804	143/619	191/522	770/651	585/642
Total	975	1121	886	912	1054	752	723	1421	1227
5 January 1973	391/574	402/724	273/732	323/677	280/774	213/635	248/571	757/570	640/554
Total	965	1126	1005	1003	1054	848	819	1327	1194
13 February 1973	337/495	417/631	251/638	283/613	279/758	216/599	254/546	677/615	546/590
Total	832	1048	889	896	1037	815	800	1292	1136

* Number on nonoiled/number on oiled

TABLE 14

NUMBER OF C. fissus LARVAE SETTLING ON SHADED FOULING PLATES (OILED MAY 1972) AT GOLETA. AS WELL AS TOTAL NUMBER SETTLING IS PRESENTED FOR EACH FOULING PLATE

	Plate Numbers								
Date	10	11	12	13	14	15	16	17	18
20 November 1972						533/490			
Total						1023			
21 November 1972					29/190	638/619	123/265	325/363	236/255
Total					219	1258	388	688	491
22 November 1972	75/418	45/251	34/137	43/85	36/149	354/383	222/266	410/414	412/324
Total	493	296	171	128	185	757	488	828	736
8 December 1972	225/345	167/521	165/386	106/222	211/395	714/709	336/456	835/648	562/481
Total	570	688	551	328	606	1423	792	1484	1043
19 December 1972	221/357	169/535	161/419	105/249	217/427	684/714	349/568		
Total	578	704	580	354	644	1398	917		
5 January 1973	275/453	240/563	203/484	149/307	263/443	648/663	352/581		
Total	728	803	687	456	706	1311	933		
13 February 1973	338/545	252/573	214/485	145/385	256/442	618/651	323/532		
Total	883	825	699	530	698	1269	855		

* Number on nonoiled/number on oiled surface

settlement of C. fissus on the fouling plates at Goleta followed by a stabilization in numbers with loss of a relatively low percentage (maximum loss estimated at 10%) of barnacles (November 1972 through February 1973) in contrast to the observation on fouling plates at Santa Catalina over the same period. At Santa Catalina, 50-60% C. fissus were lost at level A. All C. fissus were lost at level D prior to November 17, 1972.

The apparently low numbers of C. fissus settlement and survival at Santa Catalina, compared to that reported at Goleta Point, were largely due to a higher sand abrasion of fouling plates at Santa Catalina Island. The fouling plates at Santa Catalina were in shallower water and during storms were heavily abraded by sand. This was evidenced by the gradual rounding of exposed corners of the fouling plates and some loss of surface textures at Santa Catalina. C. fissus also settled and survived in much higher numbers in sheltered crevices and sheltered fouling plates used in other experiments being conducted simultaneous at Santa Catalina, than on the fouling plates used in these experiments.

An algal film developed on the unoiled surfaces prior to oiled surfaces. The algal film became abundant on the oiled surfaces in January and February 1973, but it should be noted that the algal were generally attached to C. fissus which by that stage formed a thick mat on the oiled surface, rather than the oiled surface itself.

It is notable that a retardation in growth of the green film in the upper intertidal zone (mainly Blidingia minima (Nageli ex Kutzing) var. minima, diatoms and blue green algae (Lyngbya spp.) by oil was recorded on wooden stakes at Santa Catalina. Similar observations were made in the lower intertidal zone at Goleta where the algal mat was composed of species of Ulva, Entermorpha, Bangia, Blidingia, and Porphyra.

To determine if temperatures to which the newly settled barnacles and/or cyprids were exposed at low tide had a significant effect on survival, fouling plates with newly settled C. fissus barnacles and cyprids were exposed to different temperatures for four hours during low tide.

There was no mortality recorded at 25°C, 30°C, 35°C, 40°C while a significant mortality (approximately 50%) was recorded at 41°C (Table 15). At lower temperatures there was actually an increase in numbers which could have been due to inaccuracy in counting (it is often difficult to see newly settled barnacles and cyprids when a fouling plate is wet as these often were) or may be due to increased settlement and/or metamorphosis of settled cyprids during the period after exposure in the constant environment chambers. The mortality recorded at 41°C was "real" in that 50 empty cyprids remained on the fouling plates. Hence, exposure at a single low tide to temperatures of 41°C for four hours will kill a high percentage of newly settled C. fissus, barnacles and cyprids. Repeated exposure on alternate low tides to lower temperatures may or may not cause similar mortalities.

TABLE 15

SURVIVAL OF NEWLY SETTLED C. fissus (BARNACLES AND CYPRIDS)
( ) INDICATES NUMBER OF DEAD CYPRIDS COUNTED

Exposure Temperature	Census	C. fissus barnacles	C. fissus cyprids	Difference
25°C	Before Exposure	2	220	
30 May 1972	After "	2	235	+35
30°C	Before "	55	31	
25 May 1972	After "	60	34	+8
35°C	Before "	0	36	
25 May 1972	After "	6	31	+1
40°C	Before "	1	15	
29 May 1972	After "	2	19	+5
41°C	Before "	0	120	
31 May 1972	After "	0	62(50)	-58

The distribution of C. fissus within its intertidal range was determined at random points in conjunction with surface substrate temperatures between January 1972 and February 1973 (Table 16). Whether the points were wet or dry, or in the sun or shade, was recorded at the time of observation, as well as surface temperature. The points may exhibit other characteristics as regards wetness or shading at other times.

Most (0.927) of the unoiled points that were wet and shaded, bore C. fissus. Slightly more than half (0.529-0.599) of all other unoiled points irrespective of shading or wetness, bore C. fissus. Only one type of oiled surface (wet and in the sun) had half of the random points populated by C. fissus (0.524). The other types of oiled surfaces only had (0.1 to 0.2) of the points populated by C. fissus with the least fraction (0.116) being recorded on the dry oiled surface in the sun.

The C. fissus population fluctuations were recorded on selected areas at Goleta Point between November 1972 and February 1973 (Table 17). These

TABLE 16

DISTRIBUTION OF C. fissus AT GOLETA POINT

Conditions	Jan-72 Q1+Q2	Feb-72 Q1	Mar-72 Q1	Mar-72 Q2	Apr-72 Q1	Apr-72 Q2	June-72 Q1	Dec-72 Q1	Dec-72 Q2	Feb-73 Q1	Feb-73 Q2	Total
OIL												
Sun-dry	2*/32	1/7	0/10	0/4	0/4	1/1	2/16	1/21	1/6	0/1	5/10	13/112 = 0.116
Sun-wet	13/19	7/15	5/7	0/3	2/7	3/5	3/7	—	—	—	—	33/63 = 0.524
Shade-dry	2/19	—	—	0/4	—	—	—	4/12	0/2	—	—	6/37 = 0.162
Shade-wet	2/5	0/1	—	—	0/4	—	—	0/2	1/3	—	—	3/15 = 0.2
NONOIL												
Sun-dry	—	2/2	0/3	2/5	1/1	5/7	7/9	1/12	0/6	12/25	18/19	48/89 = 0.539
Sun-wet	11/12	6/12	14/24	15/30	9/30	28/35	7/18	—	10/14	10/12	8/10	118/197 = 0.599
Shade-dry	—	—	—	0/3	0/1	—	—	2/3	1/2	3/5	3/3	9/17 = 0.529
Shade-wet	2/2	3/3	1/2	1/1	0/2	—	—	—	16/16	7/7	8/8	38/41 = 0.927

* Number of C. fissus/number of random points
Q = Quadrat

TABLE 17

NUMBER OF C. fissus ON NATURALLY OILED AND UNOILED AREAS
(2.54175 cm x 2.54175 cm) AT GOLETA POINT

Area #	Substrate	12 Nov	21 Nov	2 Dec	17 Dec	16 Jan	15 Feb	Range	% Δ
1	oil	68	86	63	85	70	73	70-86	18.8
3	oil	31	18	25	24	22	24	22-31	29
4	oil	34	37	25	27	26	33	25-37	21.6
7	oil		17	29	34	31	37	17-37	54
9	oil		15	13	16	10	7	7-16	56.25
2	unoiled	126	173	162	166	76	86	76-173	56
5	unoiled	54	36	37	41	56	85	37-85	56.4
6	unoiled	79	89	103	93	81	70	79-103	23.9
8	unoiled		81	81	79	67	70	67-81	17.2
10	unoiled		19	38	26	31	28	19-38	50

% Δ is the magnitude of the range expressed as a percentage of the most C. fissus recorded in the area in a single count

data cannot be interpreted as representing population density at Goleta Point because they were chosen for ease of making repeated observations. Population fluctuations on oiled and unoiled surfaces ranged from 17% to 57%. Fluctuations appeared slightly greater (average 40.7%) on the unoiled than oiled (average 35.9%) surfaces. However, this could be a factor of site selection.

SECTION V
DISCUSSION

The experiments and field observations in this study were designed to determine the physical effects of a heavy asphaltic oil after it had dried on intertidal substrates. Analysis of Santa Barbara crude oils collected from the intertidal zone show that weathering and degradation is more rapid on the outside of a piece of tar than on the inside [12]. In other words an outside skin of highly degraded oil frequently covers a center of less weathered petroleum compounds. Therefore organisms on the outside of a layer of solid tar are not in contact with any undegraded light toxic components beneath the outer degraded tar layer.

Most of the effort in this study was directed at dry weathered tar but some observations were made on tar that was sticky. No larval settlement was ever observed on sticky tar in the field. This is partly because it provides an unstable substrate as it melts at low tide. This is evidenced by the almost stepwise rise in temperatures of sticky tar. The sticky tar probably contains some water in addition to lighter hydrocarbon compounds not found in weathered tar. As the temperature rises and the tar gradually melt's some of the water would be released and the rise in temperature slowed by evaporative cooling. Hence, the almost stepwise rise in temperature superimposed on the straight-line temperature increase.

Other field and laboratory temperature changes are directly comparable to the normal black body effects. The shiny fresh oil surfaces (both liquid and on rocks) undergo the most rapid rise in temperature and the dull weathered surfaces a slower rise in temperature. After 2 years weathering in the laboratory, the oiled surfaces often did not exhibit as great an increase in temperature as the unoiled surface. However, the initial rate of temperature increase was always faster on the surface oiled with a thin layer of oil than the unoiled surfaces. Hence, the old oiled surfaces are exposed to elevated temperatures for longer periods than the unoiled surfaces. (These laboratory weathering periods are not related to field weathering periods).

Data obtained on fouling plates, wooden stakes, and natural substrates where other factors such as surface wetness, shading, and reflection from surrounding objects influence temperature, support the laboratory observations. All experimental observations on oiled surfaces were on oiled surfaces with only a thin layer of oil. The observations on natural surfaces were on surfaces with from 0.5 to 2.5 cm dry oil.

As fouling plate and wooden stake surfaces aged there was a loss of black oil from the surface so that after about 5 months in the field it was often difficult to visually determine oiled from unoiled surfaces by their colors when dry. The oiled surfaces still became darker when wet and were readily distinguished from unoiled surfaces. This is important because the larvae of many invertebrates are attracted to settle on either light or dark surfaces depending on the species. The field asphaltic deposits remained dull black when wet or dry and were darker in color than the silicified shale. The shale was dark brown when wet and a mid brown when dry.

Four patterns of C. fissus larval settlement emerged.

1. Larval settlement was more abundant on unoiled than oiled fouling plates when the plates were oiled for 6 weeks or less.

2. Larval settlement was more abundant on unoiled than oiled fouling plates at the extreme upper level of the settlement zone.

3. Larval settlement was more abundant on oiled than unoiled fouling plates after the fouling plates were oiled 8 weeks or longer.

4. Larval settlement was more abundant on unoiled than oiled fouling plates at very high densities.

The initial preference for unoiled surfaces suggest that the larvae preferred not settle on the oiled surface until certain components and/or change in surface texture of the oil. Analysis of oiled fouling plates showed that there was indeed some weathering of fouling plates by 9 weeks exposure. Barnacle larvae actively search substrates prior to settlement, and they react both to chemical compounds and to surface texture [3,5].

Field observations after the Santa Barbara oil spill indicated that C. fissus was not observed settling on oil until about 10 months after the oil spill [7] while in previous field experiments the present author reported C. fissus settling on oiled rocks within 6 months of a January 1970 contamination and on oiled fouling plates within 9 weeks [10]. The long lag phase recorded in 1969 may have been due to several factors; the seasonal settlement pattern of this species in the area; poor field observations; longer drying period for the thicker layer of oil; low recruitment in the Santa Barbara Channel in spring 1969; substrate temperatures. C. fissus does not settle during warm summer months, so that while substrates may have been suitable for settlement after the May-June settlement period but prior to the September-October larval settlement, there was no settling larvae available during this period. In 1969 there was also reoiling of surfaces and oil layers were frequently

thicker than those studied in 1970. Hence, a longer drying and weathering period may have been necessary. Substrate temperature may have been most important because the surfaces studied in 1970 were shaded by a pier while those observed by Nicholson and Cimberg [7] were on exposed rocky surfaces.

Some of the tar was stable enough to support larval settlement as early as March 1969 when B. glandula was collected from oiled substrates. However, balanoid barnacles have basal calcareous plates which separate the animal from the substrate after settlement and metamorphosis. C. fissus is lacking in these basal plates. Hence, the young C. fissus barnacles are directly exposed to an oiled substrate while the young balanoid barnacles are protected by a calcareous layer.

The preference of larvae for unoiled over oiled surfaces at upper-intertidal levels reflects temperature stress caused by the black surfaces. Laboratory experiments indicated high mortalities at temperatures above 40°C for four hours. Temperatures over 40°C are recorded on these fouling plates. Temperatures are higher on dry oiled than dry unoiled surfaces and high intertidal areas are exposed to these high temperatures for longer periods than lower intertidal areas. If temperature stress at low tide is the only factor causing this trend at high intertidal levels, after the initial 8-week lag phase on the fouling plates, one would expect more numerous settlement on oiled than unoiled surfaces followed by a higher mortality on the oiled than unoiled surfaces shortly after larval settlement. Barnacles in general, and C. fissus in particular (author, unpublished data) settle more abundantly on dark surfaces than light surfaces. Unfortunately larval settlement was so sparce at upper levels that the error involved in making accurate field counts on wet fouling plates as soon as they were exposed at low tide made it impossible to determine the pattern of larval settlement prior to intertidal exposure and survival pattern after intertidal exposure.

In general, within the C. fissus zone of larval settlement, C. fissus settled more abundantly on oiled than unoiled surfaces. In other words, settlement was more abundant on dark than on light surfaces. This is in agreement with larval settlement patterns reported elsewhere in barnacle settlement. However, the reversal of this trend when the settling populations become dense has only been recorded in serpulid polychaetes prior to this [11]. Other barnacle species are recorded maintaining a minimum distance between individuals [5] while Crisp [2] found a relationship between separation distance and the length of the previously settled spat and length of cyprid. This spacing is a result of the searching activities of the cyprids and allows the barnacles enough space to grow to maturity. Therefore, as a settling area, in this case the oiled area, becomes crowded with settling and already settled barnacles, the settling barnacles find the unoiled area where there are less settled barnacles, more attractive.

C. fissus settlement was more abundant at Goleta than at Santa Catalina Island during experiments with fouling plates in fall 1972. This is

probably due to the greater sand abrasion of fouling plates at Santa Catalina Island than at Goleta. The Santa Catalina Island plates were closer to the shore, in shallower water, and showed more visible evidence of sand abrasion than the fouling plates at Goleta. Fouling plates at Santa Catalina Island that were sheltered from sand abrasion in another project, showed larval settlement comparable to that observed at Goleta.

Another possible explanation is that C. fissus larvae at Goleta had evolved a tolerance to seep oil in the area. This is unlikely because the larvae are pelagic and the larvae settling in the area have no doubt been transported there from other areas on ocean currents.

Field data showed that while C. fissus can settle and survive on surfaces with a layer of dry asphalt, the numbers of barnacles were lower on the oiled than the nonoiled surfaces. However, data over a three month period suggested that while survival varied on oiled and unoiled surfaces there was no defined trend for greater survival on the oiled or unoiled surfaces. Hence, the field data supports the contention that population differences on oiled and nonoiled surfaces are largely determined during larval settlement and/or in the period soon after larval settlement.

Data on the intertidal distribution of species on vertical wooden stakes showed that in upper intertidal algae and Teredinae, there was a definite depression in upper intertidal distribution of these species in the presence of oil. This same experiment did not detect any difference in C. fissus distribution. However, as few C. fissus settled on the wood, these data were not considered meaningful for C. fissus.

SECTION IX
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SECTION VIII APPENDICES

APPENDIX 1

THE MINIMUM, MAXIMUM, AND MEAN TEMPERATURES (°C) RECORDED ON OILED NATURAL SURFACES AT GOLETA POINT (1972-1973)

	Sun dry	Sun wet	Shade dry	Shade wet
January	21.5-28.0;25.0	20-24;22.3	18.0-21.5;19.5	19.0-23.0;20.5
February	28-32.2;30.3	24-28.8;25.9	_____	19.6
March	25-30;27.7	22-27.5;24.4	_____	_____
	25.0-29.1;27.3	27-3 .0;29.0	18.9-24.8;20.2	_____
April	25-26;25.3	18.8-24.6;21.3	_____	16.3-19.6;17.25
	23.0	22.0-25.8;24.3	_____	_____
June	25.3-33.5;30.3	24.3-26.9;25.3	_____	_____
December	24-29;26.9	_____	20.7-23.0;21.55	_____
	23-28;25.8	_____	20.5-21.5;21	20-20.5;20.3
February	23.0	_____	_____	_____
	22.8-27.5;23.8			

APPENDIX 2

THE MINIMUM, MAXIMUM, AND MEAN TEMPERATURES (°C) RECORDED ON NON-OILED NATURAL SURFACES AT GOLETA POINT (1972-1973)

	Sun dry	Sun wet	Shade dry	Shade wet
January	_____	20.0-23.0;21.0	_____	19.0-20;19.5
February	29.0-29.5;29.25	23.5-27.2;25.2	_____	19.5-22.2;19.7
March	24.26.5;24.8	22-27;24.1	_____	20.6-21.0;20.8
	22.9-25.1;24.2	24-33;26.6	19.0-22.6;19.8	21.4
April	19.8	19.0-25.1;22.3	16.0	16.5-19.8;18.1
	22.3-23.8;23.1	22.0-30.1;25.4	_____	_____
June	24.9-27.4;26.8	23.1-27.8;25.6	_____	_____
December	23.0-29.5;25.4	20.2-25.5;22.8	21.5-26.5;23	_____
	24-26;25.6	20.5-26.0;23.4	21-25.5;23.2	18.5-23;21.1
February	19.5-24.0;21.6	19.5-22.5;21.2	18.2-20.8;19.1	16.6-19.0;17.7
	20.5-25.5;22.9	20.0-22.0;20.9	19.7-20.2;20	18.5-20.4;19.3

APPENDIX 3

LARVAL SETTLEMENT ON ORDERED FOULING PLATES

Plate	Number of *C. fissus*
1	167
2	196
3	77
4	138
5	49
6	18
7	65
8	94
9	89
10	82
11	36
12	42
13	80
14	62
15	53
16	70
17	34
18	32
19	22
20	39
21	64
22	55
23	37
24	48
25	34
26	30
27	22
28	12
29	0
30	40
31	28
32	6

$r_s = 0.28$

As N is larger than 30, the significance is tested by the formula.

$$t = r_s \frac{N-2}{1-r_s^2}$$

$$= 1.61$$

$t = 1.695$ at the 5% level of significance when $df = (N-2) = 30$.
Hence t is not significant at the 5% level.

APPENDIX 4

PERCENTAGE OF FOULING PLATES AT GOLETA WITH MORE BARNACLES ON OILED THAN UNOILED SEGMENTS

Number barnacles/fouling plate	%
100 - 200	100
200 - 300	100
300 - 400	100
400 - 500	80
500 - 600	100
600 - 700	86
700 - 800	72
800 - 900	86
900 - 1000	86
1000 - 1100	78
1100 - 1200	100
1200 - 1300	25
1300 - 1400	0
1400 - 1500	0

$r_s = -0.718$

When N = 14, $r_s = 0.645$ at 1% significance level. Therefore, r_s is significant.

APPENDIX 5

PERCENTAGE OF FOULING PLATES AT SANTA CATALINA ISLAND WITH MORE BARNACLES ON OILED THAN UNOILED SEGMENTS

Number barnacles/fouling plate	%
0 - 10	60
10 - 20	60
20 - 30	80
30 - 40	0
40 - 50	100
50 - 60	-
60 - 70	100

$r_s = 0.053$

When $N = 7$, $r_s = 0.893$ at 1% level of significant. Therefore, r_s is not significant.